Online Learning for Autonomous Navigation in Unstructured Environments by Unmanned Ground Vehicles (UGVs)

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Context

The PhD thesis will take place in a joint project with Jonh Cockerill Defense and ENSTA funded by AID (Agence Innovation Défense) through CIEDS (Centre interdisciplinaire d'études pour la Défense et la Sécurité) of Institut Polytechnique de Paris. So, this position is subject to access restrictions under applicable regulations. Only eligible candidates will be considered.

Background

Autonomous navigation for Unmanned Ground Vehicles (UGVs, e.g., Figure 1) in unstructured environments presents significant challenges due to the dynamic and unpredictable nature of such terrains. Traditional non-learning-based methods often rely on geometric representations and predefined maps, which are insufficient for handling the complexities of off-road navigation. Recent advancements in machine learning for LiDAR-based and vision-based semantic segmentation have shown promise in improving the perception capabilities of UGVs by providing more detailed scene understanding. This is made possible thanks to dedicated datasets such as RUGD [6] (Figure 1) or RELLIS [2], even though these datasets are limited in size compared to those for autonomous driving.

However, most existing methods often struggle with domain generalization, which is a particular concern in unstructured environments where domain shifts can be strong, and where precise characterization of the terrain is more difficult than in autonomous driving while crucial for efficient navigation. A possible approach we want to pursue to tackle this difficulty is to provide online learning capability to quickly adapt a model to the current environment, or to transfer psuedo-labels from one modality to another (e.g., [5, 1] for vision-based traversability learning).



Figure 1: Left: Illustration of the RUGD dataset [6]. Right: the Barakuda robot from Shark Robotics available at ENSTA for autonomous off-road navigation.

Research Objective

The primary objective of this PhD research is to develop advanced online learning techniques for autonomous navigation in unstructured environments by UGVs. Building upon the foundational work in LiDAR semantic segmentation with spatial context and auxiliary tasks [4], this research aims to enhance the adaptability and robustness of UGVs in real-time, enabling them to navigate diverse and challenging terrains effectively. A key focus will be on integrating self-supervised learning techniques to leverage unlabeled data and improve model generalization [7]. This work will benefit from the existing open-source autonomous navigation stack [3] developed at ENSTA, see https://github.com/LARIAD/Offroad-Nav

Research Questions

1. **How can online learning techniques be integrated with LiDAR semantic segmentation to improve real-time adaptability in unstructured environments?**
   - Investigate the use of continual learning and meta-learning approaches to enable UGVs to adapt to new environments on-the-fly.
   - Develop strategies for detecting and mitigating failures due to sensor noise, occlusions and other real-world challenges in real-time, to safe and reliable operation of UGVs.
2. **What are the most effective methods for learning visual representations which are robust against domain shifts?**
   - Evaluate different methods for learning robust and adaptable features in the pre-training phase.
   - Develop novel 3D-vision architectures and training pipelines (eg. using auxiliary tasks) to enhance the models' ability to generalise across various terrains and conditions.
3. **How can self-supervised learning techniques be completed to enhance model robustness and adaptability?**
   - Explore self-supervised learning methods to leverage unlabeled data for improving feature representation and generalization other than geometric features on point clouds, through incorporating data from other modalities such as IMU and RGB sensors to increase robustness.

Expected Outcomes

- **Enhanced Perception and Navigation Capabilities:** Develop models and algorithms that significantly improve the navigation capabilities of UGVs in unstructured environments.
- **Robustness and Adaptability:** Create robust and adaptable systems that can handle real-world challenges, such as quick context modification or strong sensor noise, ensuring reliable operation in diverse conditions.
- **Contributions to the Field:** Development of new models for robust navigation in unstructured environments. Validation of the proposed approaches on standard datasets and on real robot experiments. Publications in major conferences and journals (IEEE-TRO, ICRA, IROS, RSS ...).

Conclusion

This PhD research aims to push the boundaries of autonomous navigation for UGVs in unstructured environments through online learning techniques. By building upon existing work in LiDAR semantic segmentation and incorporating advanced learning methods, including self-supervised learning, we seek to develop robust and adaptable systems that can navigate diverse and challenging terrains effectively. The outcomes of this research are expected to have significant implications for various applications, including but not limited to search and rescue, environmental monitoring, and military operations.

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